

Review Article

Disinfecting Water: Electrocoagulation as an Efficient Process

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To cite this article:Djamel Ghernaout, Mabrouk Touahmia, Mohamed Aichouni. Disinfecting Water: Electrocoagulation as an Efficient Process. *Applied Engineering*. Vol. 3, No. 1, 2019, pp. 1-12. doi: 10.11648/j.ae.20190301.11**Received:** December 14, 2018; **Accepted:** December 28, 2018; **Published:** January 24, 2019

Abstract: Electrocoagulation (EC) process has been largely found efficient in terms of pathogens removal. This literature review focuses on describing the key killing microorganisms' pathway followed throughout the EC technique. The pathogens removal route using EC is deeply assessed following the practical experimentation realized during these last years. Physical elimination and chemical deactivation pathways are suggested for bacteria reduction procedure throughout the EC method employing Fe/Al anodes: (1) entrapping pathogens in flocs, (2) destabilizing negatively charged microbes through sweep flocculation, and (3) demobilizing bacteria cell envelopes upon electrochemically formed reactive oxygen species or direct impact of the electric field. Finally, deepest investigation works on microbes' removal through EC are more called to promote the industrial applications of this performant technology.

Keywords: Electrocoagulation (EC), Electrochemical Disinfection, Electric Field (EF), Electro-Fenton (EF), Microorganisms

1. Introduction

Deteriorating the present freshwater and employing natural water resources unsustainably have generated technology challenges for treating water to satisfy the humankind [1, 2]. Polluting microbiologically natural water sources complicates the harmful impact to all existing living-beings in Earth [3]. Particularly, pathogenic microbes like bacteria, viruses, algae and fungi are largely observed in all water sources [4-7]. These pathogenic microbial elements form acute water borne diseases and deadliness happens in through the entire world especially in poor nations. Therefore, the killing pathogenic microorganisms in aquatic media is more than vital for both humans, animals, and plants [8-10].

As a rule, pathogenic organisms are demobilized and destroyed completely throughout the disinfection process [11]. Conventionally, killing microorganisms is largely realized upon pre-oxidation employing chlorine based oxidants and

chemical coagulation processes [12, 13]. However, the principal problem linked to these classical techniques is that both the safety and quality of the disinfected water are not assured [14]. This may be attributed to the fact that the microorganisms are mainly different from biological and structural points of view. Demobilizing and eliminating performance for a specific method is a function of the microorganisms' physical and biological features such as lateral size, layer number and surface functional groups and biological strains such as gram-positive, gram-negative and shape of the bacteria. To ameliorate killing microorganisms, a deep knowledge comprehension of killing microorganisms' phenomena has a crucial contribution. Choosing a convenient technique necessitates a clear proof of killing microorganisms in water [3].

2. Water Disinfection Background

For killing microorganisms in water, different techniques

have been mentioned [3]. Nevertheless, chlorination is the most used and common method for killing microorganisms. Chlorinating water implies injection of chlorine and/or chlorine similar chemical products that demolish the poisonous bacteria [15]. In terms of efficiency and cost, it is the most preferred disinfectant for most toxic bacteria. Regardless of several benefits, chlorine-killing microorganisms' method shows many negative sides. If chlorine products are introduced into water at elevated degrees, pathogens enter spontaneously in assemblages avoiding their demolition [3]. Therefore, they begin to be reluctant to Cl_2 in the course of disinfection. Moreover, the emergence of poisonous disinfection by-products (DBPs) such as ClO_2 , ClO^\cdot , and ClO_4^- is the serious inconvenient [16]. Chlorinating water as well forms unpleasant odor and taste in potable water [17]. Consequently, considerable different techniques were

tested for treating microbiologically water [18]. Figure 1 displays a rating of different methods tried heretofore for water killing microorganisms. Like the chlorination process [19], additional techniques have as well been investigated comprising:

- (1) Chemical method founded on ozone, silver, copper, ferrate, iodine, bromine, hydrogen peroxide and potassium permanganate,
- (2) Physical manners like ultraviolet (UV) illumination, ultra-sonication, pulsed electric fields (EFs), irradiation magnetic-induced enhanced disinfection and microwave system, and
- (3) Physicochemical processes like photocatalytic microbes' deactivation employing metal oxide, carbon-based and polymer-based nano-photocatalyt, photodynamic disinfection techniques [20].

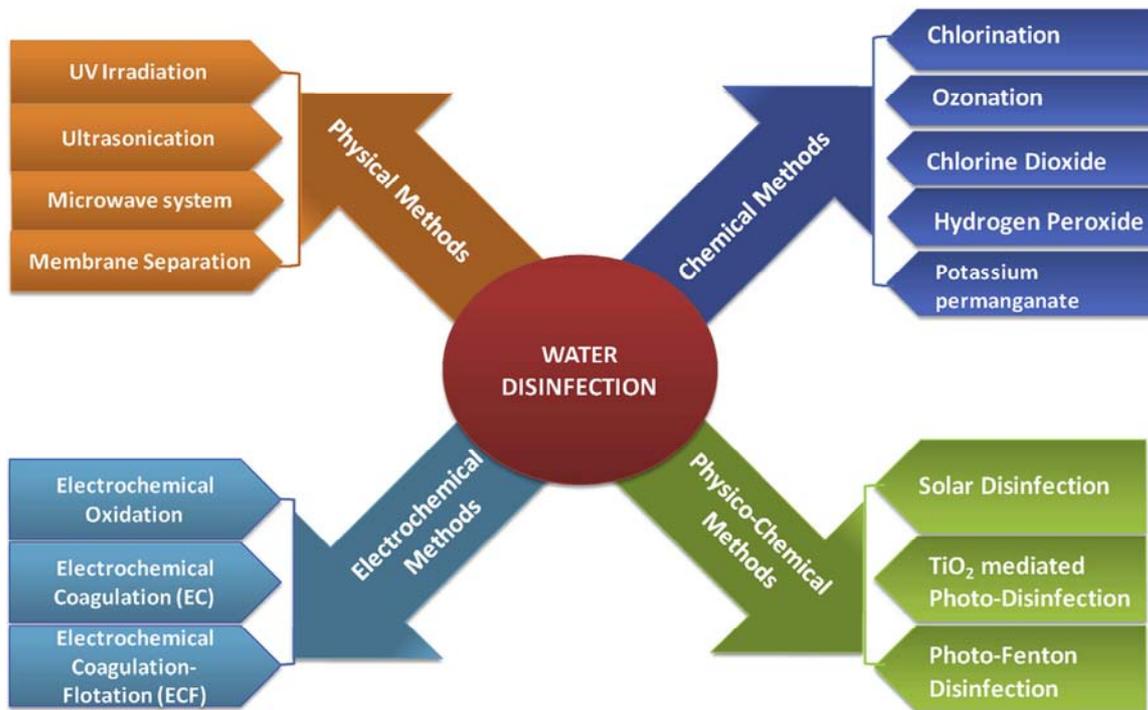


Figure 1. Different technologies used for treating water in matter of pathogens removal [3].

One of these, solar driven photo-catalysis for deactivation of microorganisms has recently attracted huge interest. This is due to the fundamental deactivation procedure, material synthesis, and appropriate reactor design for water disinfection method during solar photocatalysis [21]. The main part of the photocatalytic techniques used in disinfecting water act upon reactive oxygen species (ROSs) like hydroxyl radical ($\cdot\text{OH}$), superoxide anion radical (O_2^\cdot) and hydrogen peroxide [22-24]. These generated ROSs induce good ion permeability, interruption of respiratory pathway and membrane rupture [25]. Even if these processes attained considerable interest as water disinfection method, they did not satisfy the permissible limit standards of disinfected residual water [26]. In fact, TiO_2 mediated photo catalytic system, UV irradiation and high intensity pulsed electrical field disinfection does not give residual disinfection. Thus,

these disinfection techniques are viewed just for primary disinfection. At the same time, eliminating microorganisms from polluted water is observed to be one of the most significant stage for potable water treatment [27, 28]. Surely, the contaminated water microbiologically had been treated upon membrane removal such as micro-filtration (MF), ultra-filtration (UF) and nano-filtration (NF) methods [29]. Nevertheless, a preliminary treatment is required to get microorganisms' removal reaching an appreciable efficiency. This may be attributed to the size of microorganisms smaller than membrane pore size generating the main inconvenient of the membrane processes. In addition, pre-treatment upon injecting coagulants prior to membrane stage has considerably improved the water quality and diminished the membrane fouling [3, 30].

3. Disinfecting Water upon Electrochemical Technologies

Recently, electrochemical demolition of pathogenic microorganisms has been largely proven [31-33]. This is because the common electrochemical methods are eco-friendly, cost-effective, amenable to automation and simple to manipulate as killing microorganisms' techniques [34-36]. Moreover, many killing microorganisms' procedures have been suggested to interpret the poisonous bacteria removal upon techniques based on EF application, which may be listed as [3, 37-39]:

1. Oxidative stress,
2. Cell wall demolition attributed to formed ROSs (oxidants) in the electrochemical device,
3. Irreversible permeabilization of cell membranes through an externally imposed electrical current, and
4. Electrochemical oxidation of vital cellular constituents upon the passage of electric current or induced EF [40].

Following the electrochemical design, a range of produced oxidants has been observed throughout the period of the process [3, 41]. As a rule, chloride-containing electrolytes generate active chlorine species (like Cl_2 , HOCl , and OCl^-) which are fundamental oxidants responsible for demobilizing pathogenic cell wall structures [42, 43].

Now, boron doped diamond (BDD) electrodes are largely employed to investigate the contribution of the ROSs such as $\cdot\text{OH}$, H_2O_2 and $\text{O}_2^{\cdot-}$ in treating microbiologically water upon electrooxidation of water [42, 44, 45]. Moreover, additional reactive oxidants such as $\text{S}_2\text{O}_8^{2-}$, $\text{C}_2\text{O}_6^{2-}$ and $\text{P}_2\text{O}_8^{2-}$ have as well been formed from the oxidation of water holding SO_4^{2-} , CO_3^{2-} and PO_4^{3-} ions, respectively [43]. In fact, the previously mentioned oxidant generation is greatly dependent on fundamental working factors like electrolyte type and its concentration, temperature, electrode materials, initial electrolyte pH, applied voltage, and the type of electrolysis [46]. Concerning the previously mentioned parameters, choosing the electrode materials is the main important parameter dictating the species and efficiency of oxidant formation. More importantly, the electrode materials must have inherent capacity to produce elevated oxidation over potential ROS. For this object, several electrode materials like lead oxide, tin oxide based dimensionally stable (DSA) anode and BDD have been largely examined. Such electrodes decrease the velocity of the oxygen production. On the other hand, commercializing, fabricating and using DSA and BDD electrodes are not easy to keep and decrease cost-effectiveness [3, 22, 47].

In addition, killing microorganisms in water employing electrocoagulation (EC) process appeared greatly since 1984

[48] and more importantly from the end of the last decade [3, 49-51]. In the EC method, sacrificial iron (Fe) [52-54] and aluminum (Al) anodes are largely used [55]. Killing microorganisms using Al electrode surpassed than that of Fe anode. However, Fe anodes eased distinguished microorganisms demolition due to the existence of Fe^{2+} and Fe^{3+} ions. At the same time, the existence of more fecal measures and pathogenic bacteria in wastewater may greatly hinder the EC abatement performance. The regular EC process passes through many procedures concurrently [56, 57]. Until now, the at hand references are not able to give enough experimental proof for assessing the accurate procedure followed whilst EC. Because of the different structural and biochemical features of every microorganism, divining the pathogenic demolition procedure is not easy to define correctly. Taking into account these characteristics, the attention is accorded here to the procedure involved during killing microorganisms in water upon the EC method.

4. EC Knowledge and Engineering

EC process may be viewed as the most captivating technique, especially if compared with chemical coagulation [58]. Indeed, EC had been largely tested in both water and wastewater treatment [59, 60] to significantly eliminate a large range of chemical contaminants (i.e., heavy metal ions, inorganic anions and organic constituent dyes, pesticides, pharmaceuticals, and personal care products) [61-63]. EC knowledge and usage has been assessed at times [64]. Throughout the last decade, EC process emerged as the most interesting alternative water disinfection to electro-chlorination and electrochemical oxidation thanks to its particular characteristics [3, 65-68]:

1. Injecting chemicals may be avoided before EC operation and shows appreciable contaminant removal possibilities.
2. Using EC four different wastewater types is well known.
3. Forming less sludge throughout EC method [69]; thus, reducing the sludge disposal cost and EC as an alternative process for classical coagulation.
4. Low energy consumption and operating cost; therefore, making EC an eco-friendly process.
5. Operationally, EC method is simple with compact reactor design and short reactive retention time.

Table 1 lists a short summary of the procedure of EC, floc generation, and sedimentation kinetics. As shown in Figure 2 (a), a typical EC process works with several stages to synergistically remove pollutants from wastewater [3]. A representative procedure in charge of the elimination of contaminants through EC is schematically illustrated in Figure 2 (b).

Table 1. Concise outline of the operation of EC, floc production, and precipitation kinetics [3, 31, 70-77].

EC features	Description
EC stages	During this method, electrochemically liberated M^{n+} ions react instantaneously with hydroxide ions (OH^-) to form <i>in-situ</i> insoluble nano-crystalline metal hydroxide/oxide coagulants (hydro-oxo-metal species) in the water (Figure 2 (a)). In addition, the monomeric metal hydroxide species may as well interact to produce polymeric metal hydroxide species. These possess the disposition to destabilize the pollutants and/or enter in the generation of particles with decreased solubility that enmeshes the contaminants. At different levels, EC method may be affected by the concentration of metal ion, the charge on the metal ionic species, the pK_a values of individual ionic species and actual pH of the solution (Figure 2 (b)). As an illustration, the positively

EC features	Description
<i>Floc formation and precipitation kinetics</i>	charged floc surface eliminates the chemical pollutants through surface complexation or electrostatic attraction. In surface complexation, it is suggested that the solubilized contaminants moiety may work as a ligand to fix metal hydroxyl particles which may further precipitate by adsorption/co-precipitation procedures. Additional benefits of the EC technique are the $H_{2(g)}$ evolution in the cathodic region playing a role in carrying the flocs to the water surface and giving additional buoyancy in the device [78]. Despite the fact that the EC technique has been largely experimented at lab scale level, pilot scale running was observed too hard to control. Pilot-scale wastewater treatment units in the industries handle thousands of cubic meters of water on a day-to-day basis. After coagulation phase, floc formation happens. Both floc generation and sedimentation kinetics of the flocs [79] play a major role in deciding the viability of the overall process. These steps have been studied, and usually assessed for conventional coagulation. The floc generation and sedimentation rates of coagulants produced in EC, on the other hand, had attracted interest only recently. It was established that EC conducts to the formation of loosely held porous aluminum hydroxide flocs; whilst conventional coagulation [80, 81], under similar conditions, leads to relatively smaller compact flocs [82]. The sedimentation rates were as well observed to be different for EC and classical coagulation [83, 84] formed sediments.

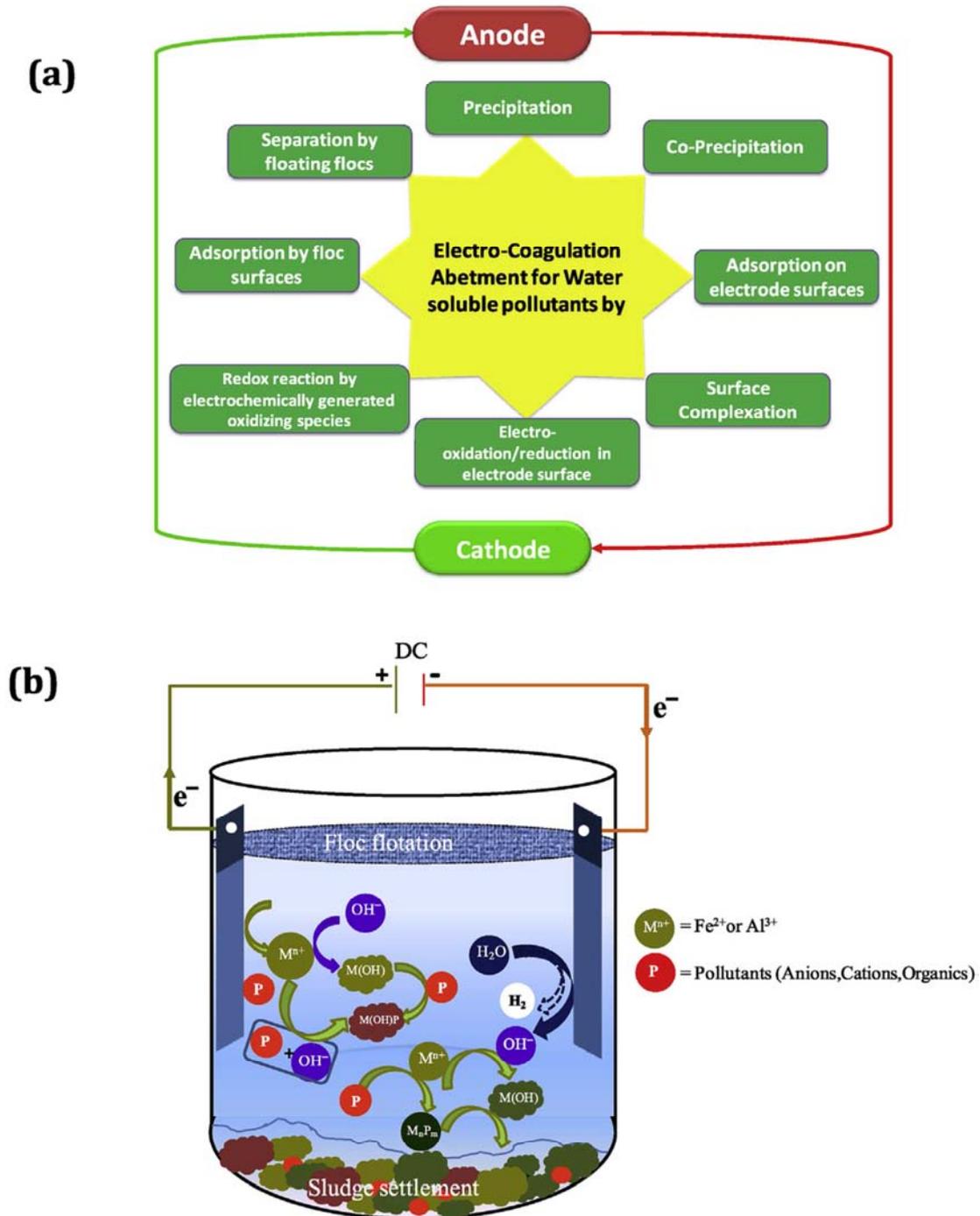


Figure 2. (a) Types of multiple phenomena responsible for removing contaminants through EC. (b) Schematic illustration of EC procedure [3].

5. Survey and Comprehension of Procedure in Charge of Microorganisms' Removal Through EC

As mentioned above, using EC technique had been tested importantly for removing pathogens from water [3]. Efficiency and variation of deleting bacteria through EC method had been followed using different solutions like synthetic water, river water, surface water, and industrial wastewater [69, 85]. Using EC technique for pathogens elimination was collected and details (such as reactor design, nature of electrode, effluent and working parameters and contaminating constituents) of each test are presented in a Table by Govindan et al. [3]. Important microbial removal was obtained by optimizing the practical factors [86]. Usually, the effect of water pH, supporting electrolyte [87], turbidity (i.e., total suspended solids (TSS)), conductivity (dissolved solids), nature of electrode, inter-electrode gap, current density, temperature, chemical oxygen demand (COD) and dissolved organic carbone (DOC) or natural organic matter (NOM) [88] on pathogens elimination had been assessed [89]. The suggested pathogens removal through EC technique implicates two main stages participating simultaneously: (1) physical elimination produced by the adsorption of coagulants to cell membranes, which then favours the entrapment of microorganisms through electrochemically formed flocs and settling, and (2) demobilizing the cell membrane structure by ROSs produced by Fe^{2+} oxidation (for iron electrodes) through dissolved oxygen existing in solution. Nevertheless, the basic features of the procedure assigned to anti-microbial work through such phenomena remain an enigma. So far, the functional groups in cell membrane composition and nature of interactions (electrostatic versus specific bonding) conducting to biomass entrapment are not well comprehended. The efficiency of EC process is function of working factors like water characteristics (pH and nature of supporting electrolyte [87]), the nature of microorganism and its concentration, the existence of co-existing ions and NOM. Many investigations examined the pros and cons impact of the interaction between these factors and cell membrane composition [90]. The researches deduced that bio-molecular cell membrane composition was modified remarkably by these factors upon variations in surface charges, hydrophobicity, steric effect, and permeabilization capacity [3].

As a rule, EC mainly eliminates microorganisms through destabilizing them by combining charge neutralization and sweep flocculation [91] with unimportant deactivation willst the operation. The destabilization operation happens through the following stages:

1. Compression of the diffuse double film surrounding the charged species upon interaction of coagulant liberated from anodic dissolution;
2. The ionic species existent in the wastewater achieve

charge neutralization through counter-ions realized from the anode surface; and

3. Aggregation of destabilized phase to produce flocs and generate a sludge blanket that entrap the colloids remaining in the solution. Moreover, producing O_2 (at the anode) and H_2 (at the cathode) may be useful for contaminations' removal thanks to coagulation and flotation of colloids [3].

Nevertheless, demobilizing electrochemically microorganisms may appear in many forms such as [90]: (a) cell death thanks to electrochemically formed antibacterial products (oxidants) significating that cell demolition happens by either the stable pores generation conducting to destabilization of cell walls, lose of their important cellular constituents and destruction of chemical gradients upon oxidants transport across transient pores; (b) irreversible permeabilization of cell wall through the applied EF [92] and (c) direct electrochemical oxidation of vital cellular components by the external EF. Consequently, the simultaneous contribution of both anti-microbial products and EF [93, 94] participate to microorganisms' killing operation. Despite the several studies performed on the subject, there is not a sufficient and consistent comprehension of deactivation procedure. Until now, the interrogation remains mysterious concerning the manner by which the applied electric current acts in cell demolition [3].

5.1. Bacteria Removal

5.1.1. Physical Elimination

The EC performance in removing *E. coli* using Fe electrodes has been proven by several researchers [31, 95]. Delaire et al. [95] focused on the contribution of physical elimination on the *E. coli* removal and realized EC tests with chemical coagulant Al_2SO_4 (alum). The interest of alum introduction was to decrease the decantation period and rapidly remove cells fixed to flocs from free cells in the remaining solution. They also studied the limitation of *E. coli* removal procedure with Fe-EC, the effect of solution pH and chemical coagulant FeSO_4 (Fe^{2+}), FeCl_3 (Fe^{3+}) and pre-synthesized ferrihydrite ($\text{Fe}^{2+}/\text{Fe}^{3+}$). An important *E. coli* reduction was attained with Fe-EC at lower pH, 4 log removal of *E. coli* at pH 6.6 and 1.9 log removal at pH 7.5. Using FeSO_4 , *E. coli* abbatment was found identical (4.3 log *E. coli* removal at pH 6.6 and 2.0 log *E. coli* removal at pH 7.5). In addition, *E. coli* abbatment is not significantly influenced in the case of FeCl_3 and pre-synthesized ferrihydrite. This fact indicates that probable modification in the colloidal surface charge at $6.6 \leq \text{pH} \leq 7.5$ has no significant effect on bacteria-precipitate surface interactions. At pH 7.5, all Fe^{2+} ions may be oxidized into Fe^{3+} at the conclusion of the technique; thus, deactivating *E. coli* throughout bactericidal Fe^{2+} ion was around zero. However, the attainment of *E. coli* removal is mostly attributed to physical elimination through flocs before settling [3].

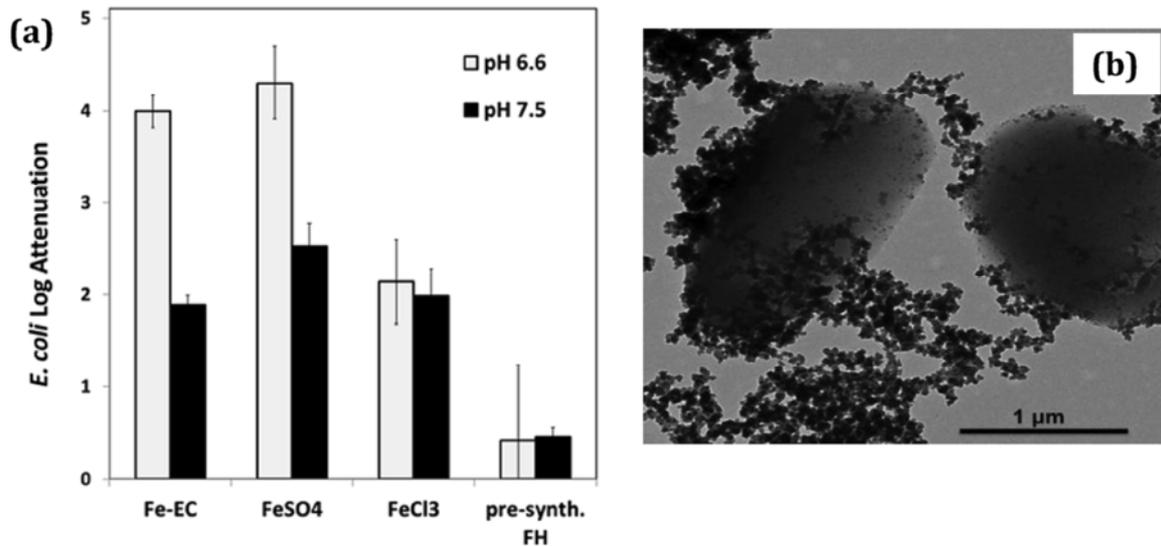


Figure 3. (a) Impact of pH on *E. coli* removal through Fe-EC and chemical coagulation with FeSO₄ salt, FeCl₃ salt and pre-synthesized ferrihydrite (FH). The Fe dosage for all experiments was 0.5 mM. (b) Transmission electron microscopy (TEM) image for association of EC precipitates and bacteria surfaces with precipitates bridging two *E. coli* cells. *E. coli* counts: 107.2 CFU/mL, Fe dosage = 0.5 mM, pH 6.6 [95].

Removing *E. coli* upon Fe-EC was approximately identical to ferric salt (Fe³⁺, FeCl₃) at pH 7.5. It additionally indicates that eliminating *E. coli* by insertion in flocs and deactivating *E. coli* surface upon bactericidal Fe²⁺ was excluded. Concerning the conceivable formation of Fe³⁺ sediments and disinfectant Fe²⁺ with Fe-EC, Fe-EC was not at a large distinction from FeCl₃ lowering in *E. coli* removal. On the contrary, *E. coli* reduction by both physical elimination and deactivation was perhaps attributed to the more delayed Fe²⁺ oxidation rate at lower pH 6.6 [3].

Eliminating physically *E. coli* through flocs produced in the device was viewed out of TEM [95]. Figure 3(b) shows the TEM image of EC sediment connected to the bacteria surface. It obviously illustrated that each single *E. coli* cell was fixed and surrounded by EC sediments. Thus, adsorbing physically may encourage the production of sediment-bacteria networks that surprisingly eliminated by means of gravitational settling.

Moreover, zeta potential analysis illustrates that the surface charge of *E. coli* and EC precipitates are observed negative at neutral pH. Attaching EC sediments to *E. coli* was probably relating to the following causes: (1) heterogeneous charges on cell surfaces, which signifies that relatively small size of EC sediment may be sensitive regarding heterogeneity constitution with various functional groups in *E. coli* surface conducting to strong fixation of EC sediments; (2) hydrophobic interactions and (3) hydrogen or covalent bonds generation among the functional groups (particularly, carboxyl group and phosphate group) existent in the cell envelope and EC sediments. Delaire *et al.* [95] affirmed that *E. coli* removal through physical elimination was the first procedure and deactivation process probably participated at lower pH. Figure 4 showed a schematically illustration of the physical removal pathway [3].

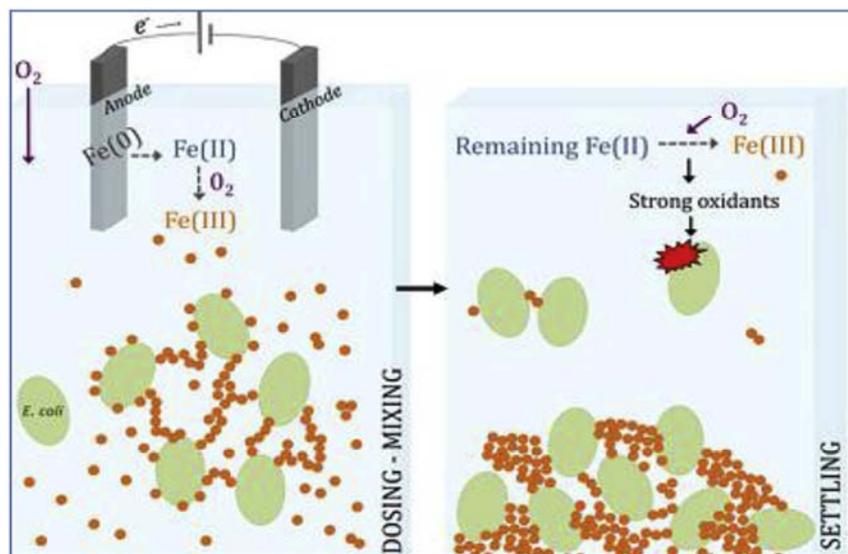


Figure 4. Schematic representation for the bacteria attenuation through Fe-EC [95].

5.1.2. Bacteria Inactivation

An additional examination of the previous predication was to show the deactivation pathway through EC technique. Delaire et al. [90] focused on the description of deactivation mechanism and the impact of bacterial surface configuration on attenuation through Fe-EC process medium containing various kinds of bacterial pollution. Indeed, they used various surface structure of bacterial strain as Gram-positive (rough) and Gram-negative (smooth). Usually, bacteria cell walls are known with four various surface functional groups namely, hydroxyl group, carboxyl group, phosphate group and amine group [96, 97]. Some researches have established that the carboxyl and phosphate functional groups possess strong tendency to fix iron (III) hydroxide sediments [98, 99]. The additional two surface functional groups do possess strong affinity to attach with $\text{Fe}(\text{OH})_{3(s)}$ [3, 100, 101].

5.2. Mechanism for Bacterial Disinfection

Govindan et al. [3] suggested and epitomized credible

pathways for biomass removal through EC from wastewater. Essentially, biomass removal is known through three fundamental ways comprising EC, electroflotation [102, 103], electrochemical inactivation, and EF inactivation [104]. In Figure 5, Govindan et al. [3] explained killing microorganisms through the different independent or synergistic processes participated pending the EC method. The most favored essential pathway in charge of microorganisms removal is physical elimination. Predominately, the destabilization of suspended pathogens happens meantime charge neutralization via physical adsorption path. The counter charge loading species coagulants (positive surface charge) and pathogens (negative surface charge) reach charge neutralization supposedly close to the anodic zone over the EC method. Indeed, the anodic disintegration of the metallic electrode increases charge neutralization between microorganisms and indissoluble metal hydroxide flocs formed as a consequence of electrochemical coagulation. This may moreover join sweep flocculation or entrapment in flocs or adsorption path [91].

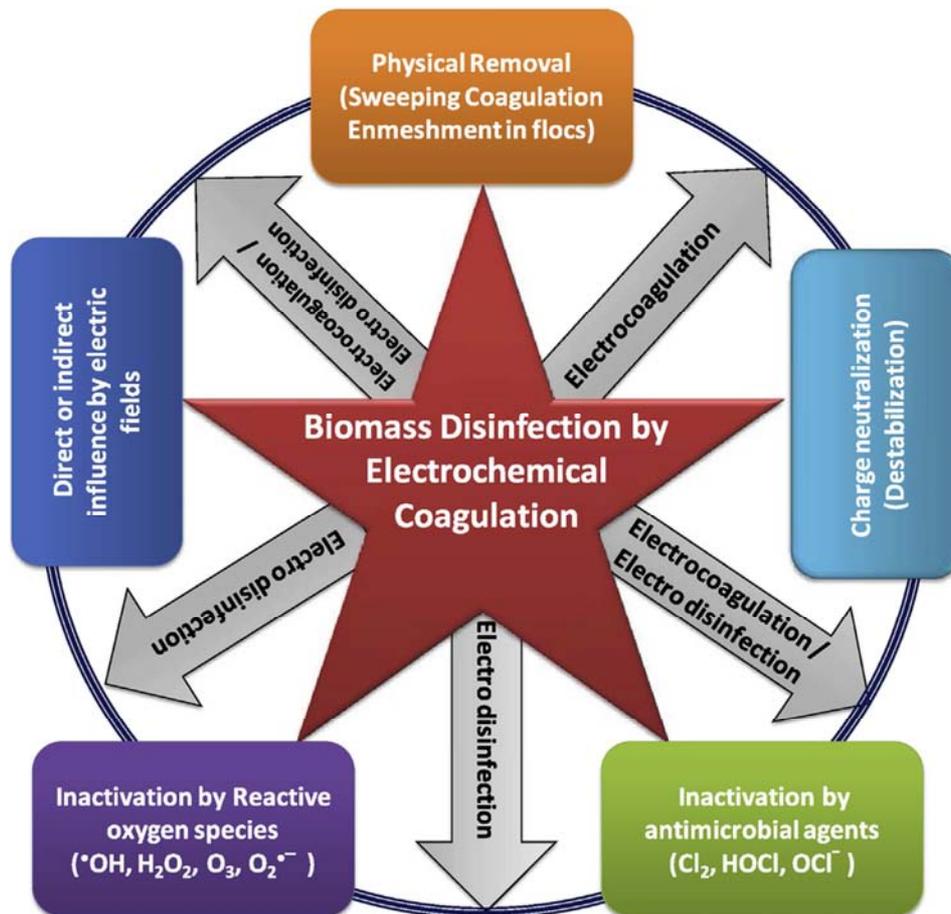


Figure 5. The possible mechanistic pathway of biomass removal across EC [3].

In addition, deactivating chemically participates in the pathogens removal throughout the electrochemical method. Demobilizing chemically happens over the two main constituents namely antimicrobial oxidants (Cl_2 , HOCl , OCl^-) and oxygen containing ROSs (O_3 , $\cdot\text{OH}$, $\text{O}_2^{\cdot-}$ and H_2O_2). The antimicrobial oxidants and ROSs, formed via electrochemical

method, are mainly function of the kind of electrolyte and electrode materials used in the electrochemical technique. Killing microorganisms chemicals are produced across the period of the electrochemical method through water electrolysis and anodic disintegration. The killing pathogens chemical products are the main purse for pathogen cell

deactivation. The antibacterial products may cross over cell envelopes and attain indispensable cellular elements, which significantly occasions the cell demolition or change of cellular arrangement. Nevertheless, producing anti-pathogens products is completely changing from Al to Fe electrodes. Indeed, Fe anodes possess more appropriate materials to form effective antibacterial products upon the EC operation over many mechanisms. However, Al electrode interposed pathogens demolition is comparatively little because of the less favorable medium for producing cleaner products. More than physical elimination and chemical demolition of microorganisms, the direct effect of the EF on pathogens may as well rationally influence the cell membrane construction. Imposing an electric current on pathogens provokes irreparable permeability of the cell walls and the WF demolish the microbes without breaking their cell envelopes [3].

6. EC vs. Electro-Fenton

An interesting approach was adopted by Anfruns-Estrada *et al.* [105] to compare the capacity of two types of electrochemical methods: EC and electro-Fenton for cleaning primary and secondary effluents from municipal wastewater treatment plants. They examined heterotrophic bacteria, *E. coli*, enterococci, *Clostridium perfringens* spores, somatic coliphages and eukaryotes (amoebae, flagellates, ciliates and metazoa). EC with an Fe/Fe cell at 200 A/m² and natural pH reached more than 5 log unit elimination of *E. coli* and final concentration below 1 bacteria mL/1 of coliphages and eukaryotes from both effluents in 60 min, while heterotrophic bacteria, enterococci and spores were more resistant. A bigger reduction was observed for the primary effluent, likely due to the fact that the flocs eliminate bigger quantity of total organic carbon (TOC), enmeshing more simply the microbiota. Electro-Fenton with a BDD anode and an air-diffusion cathode that generates H₂O₂ on site was primarily experimented at pH 3.0, with big or even total demolition of microorganisms during 30 min. A more efficient microbial elimination was obtained comparatively with EC thanks to [•]OH produced throughout Fenton's reaction. A more rapid killing microorganisms was detected for the secondary effluent due to its lower TOC concentration, letting the attack of bigger amounts of electroformed oxidants on microbes. Wastewater killing pathogens through electro-Fenton was as well realizable at natural pH (~7), proving identical elimination of active microbes as a consequence of the synergistic role of produced oxidants such as active chlorine and coagulation with iron hydroxides. A sequential EC/electro-Fenton treatment (30 min each) was more efficient for a combined decontamination and disinfection of urban wastewater.

7. Conclusions

Discussing the reliable microbes' removal pathways during the EC process guarantees that this electrochemical method may be presented as a viable instrument for microorganisms'

elimination. Removing microbes upon EC functions in the form of the three key mechanisms: (1) Destabilizing pathogens through electrochemically formed flocs; (2) Deactivating microorganisms upon electrochemically generated ROSs and bactericidal products throughout electrolysis; (3) Deactivating the cell membrane of the microbes upon direct application of the EF.

Removing microbes from water has been satisfactorily realized employing EC process using Fe and Al metallic plaques outperforming the classical coagulation. The effect of physicochemical variables, such as pH and time, electrode metal, supporting electrolyte and organic matter on microbes' elimination was largely investigated. A sensible pathogens' removal was obtained upon well-designed situations in various kinds of wastewater. For microbes' demolition, organic matter concentration, supporting electrolyte and electrode metal influence microbes demolition pathway and greatly determine the kind and ratio of ROSs formation.

There is no doubt that EC has been importantly investigated for removing microorganisms, supplementary researches are urgently needed to expand pilot-scale solutions. In addition, the present expertise does not give a pertinent comprehension of algae and virus elimination pathway. In industrial uses, because of the simultaneous existence of pathogens and organic matters in wastewater, biofouling apparition is a difficult issue if membrane processes are coupled with EC. Yet, great efforts remain to be performed to examine pathogens removal through EC as a pre-treatment for membrane processes. With a view to suggesting the EC method for large-scale wastewater treatment, electrode passivation, disinfection by-products, and engineering cost estimation have to be deeply assessed.

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